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(71) Applicant
The General Electric Company p. l. c.

(Incorporated in United Kingdom)

1 Stanhope Gate, London W1A 1EH

(72) Inventors
George Antony Georgiou
Anthony Christos Boucouvalas

(74) Agent and/or Address for Service
H. V. A. Kirby
Central Patent Department (Wembley Office), The General Electric Company p. l. c., Hirst Research Centre, Wembley, Middlesex HA9 7PP

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G2J GF

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GB 1494535

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G2J
Selected US specifications from IPC sub-class G02B

(54) Optical fibre filter having tapered sections

(57) A filter with a tailored output characteristic for example useable as a comb filter is fabricated by producing two or more biconical tapered portions in a coaxial optical fibre 10. The manufacture is controlled so that the resulting filters have specified pass-band characteristics. The fibre may comprise a central rod waveguide, an intermediate cladding, a tubular waveguide and an outer coating layer.

Fig. 4.

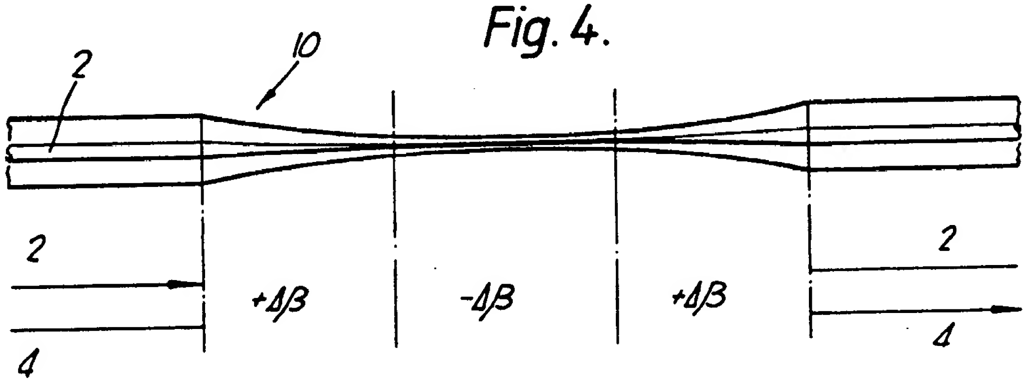

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Fig. 1.

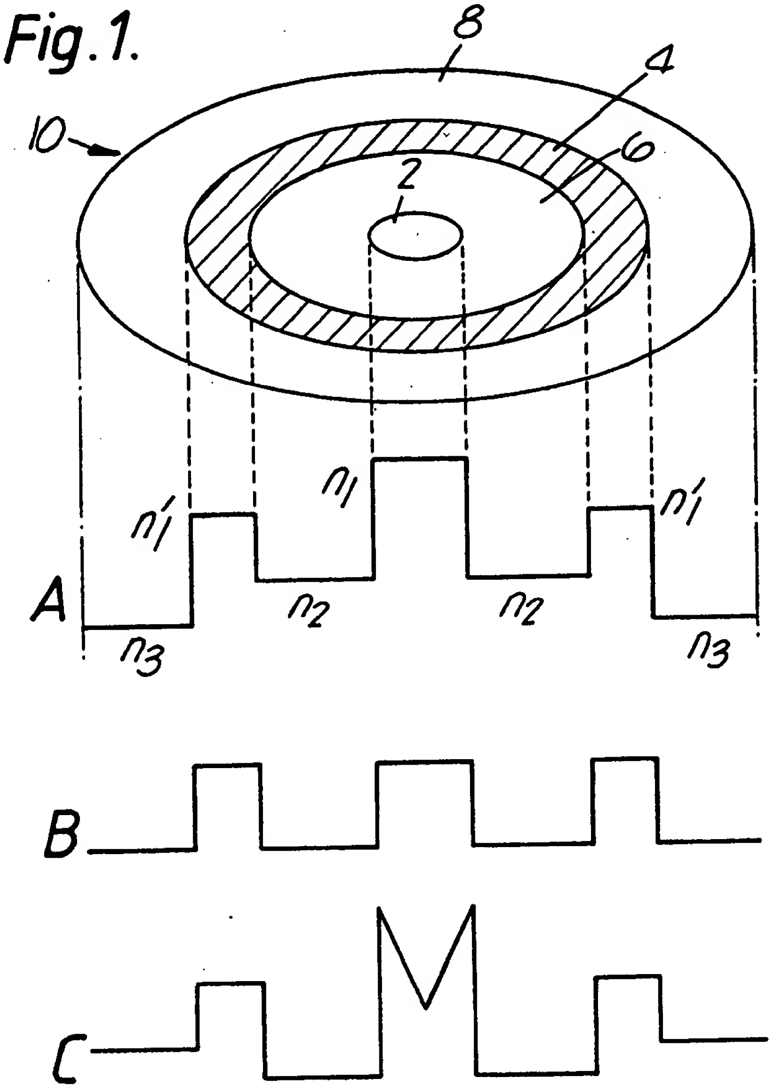
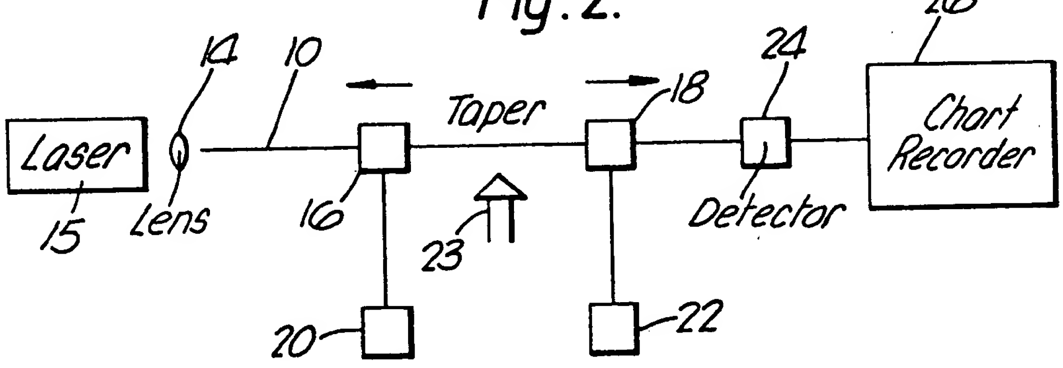

8
4
10
6
2
n_1'
n_1
n_1'
A
n_2
n_2
n_3
n_3
B
C

Fig. 2.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14
10
24
Taper
18
Chart Recorder
Laser
15
Lens
16
23
Detector
20
22

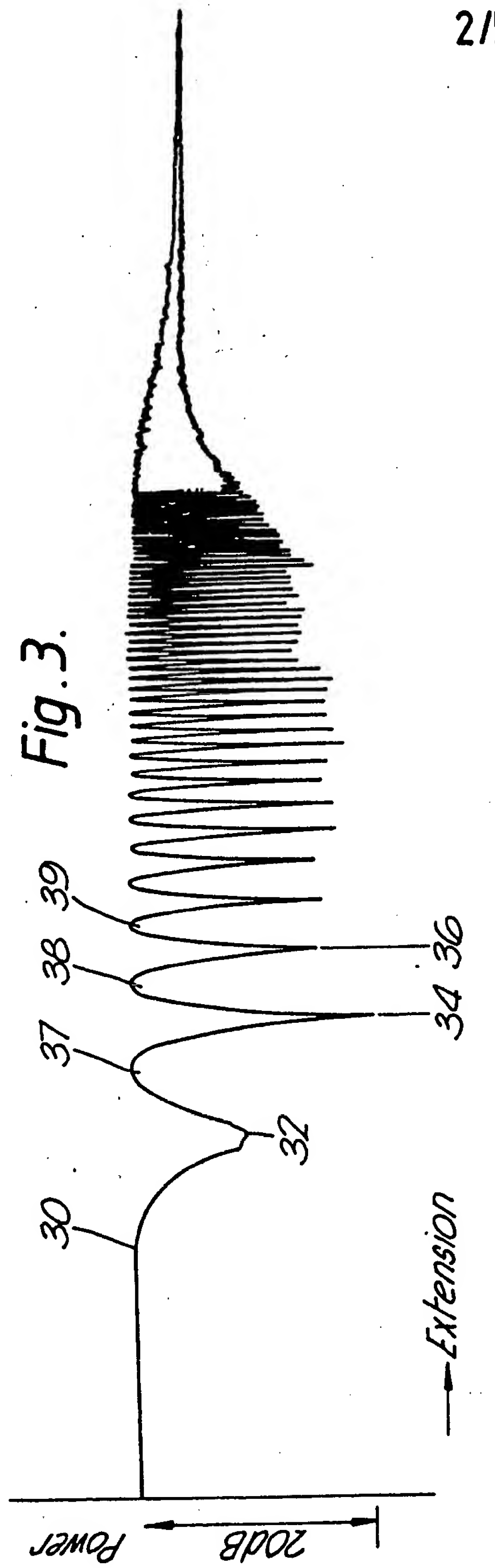

Fig. 3.

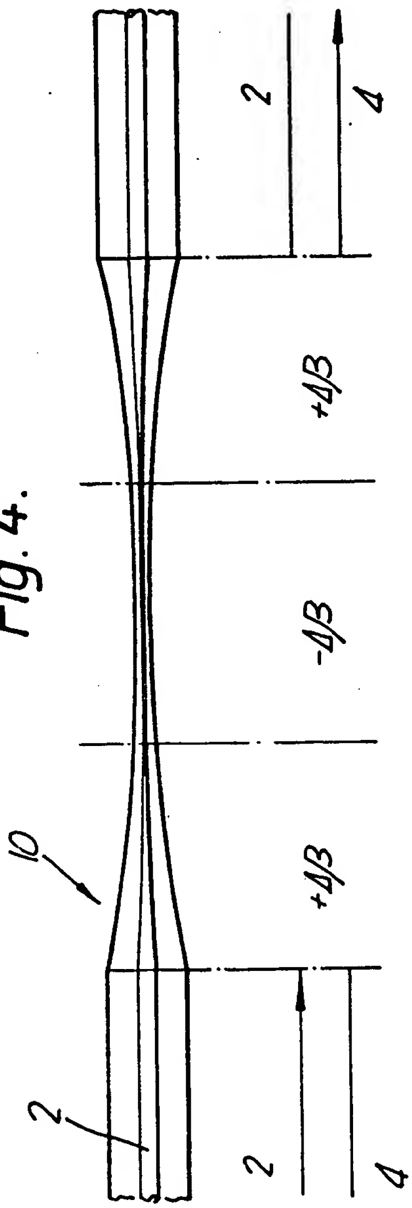

Fig. 4.

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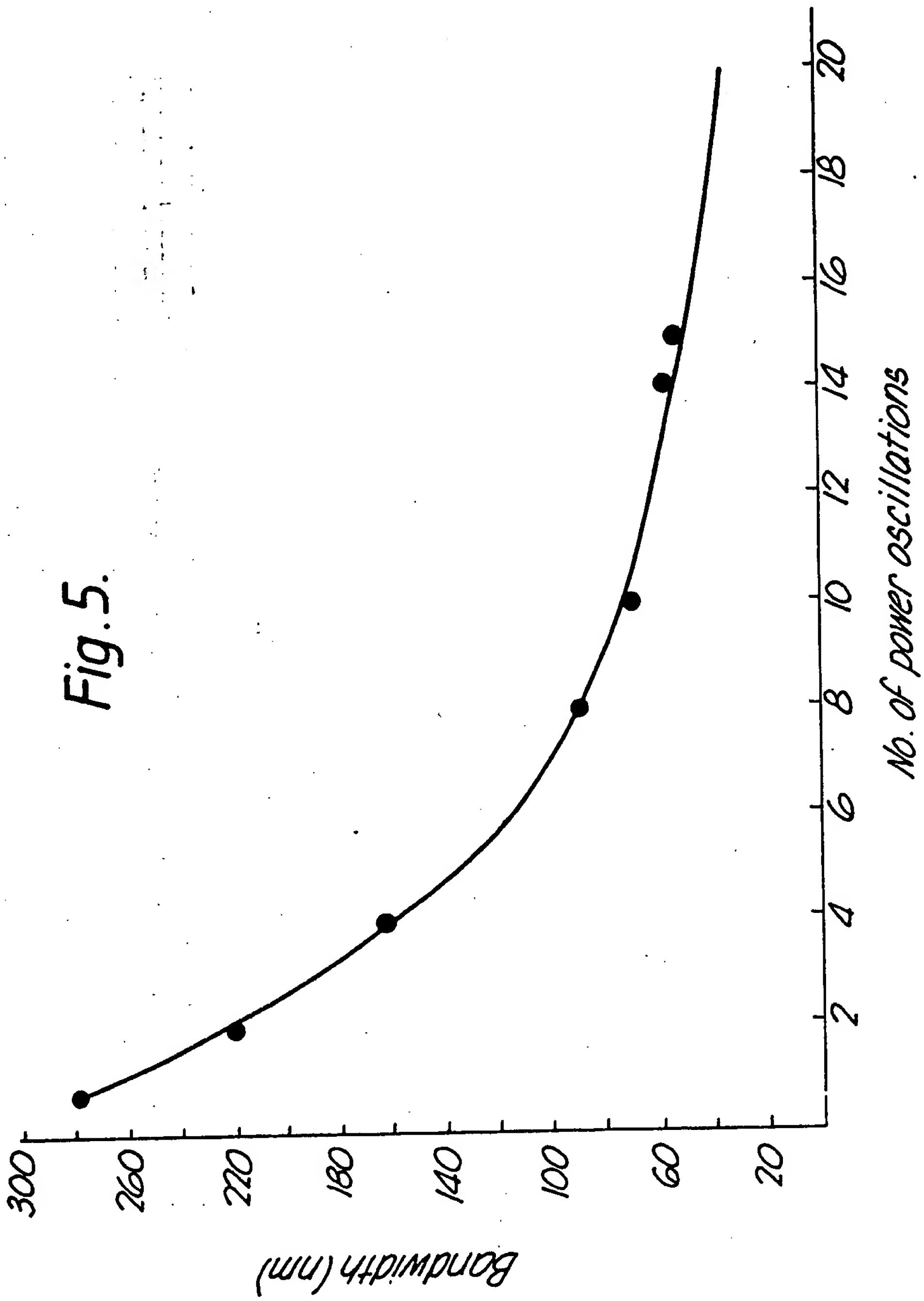
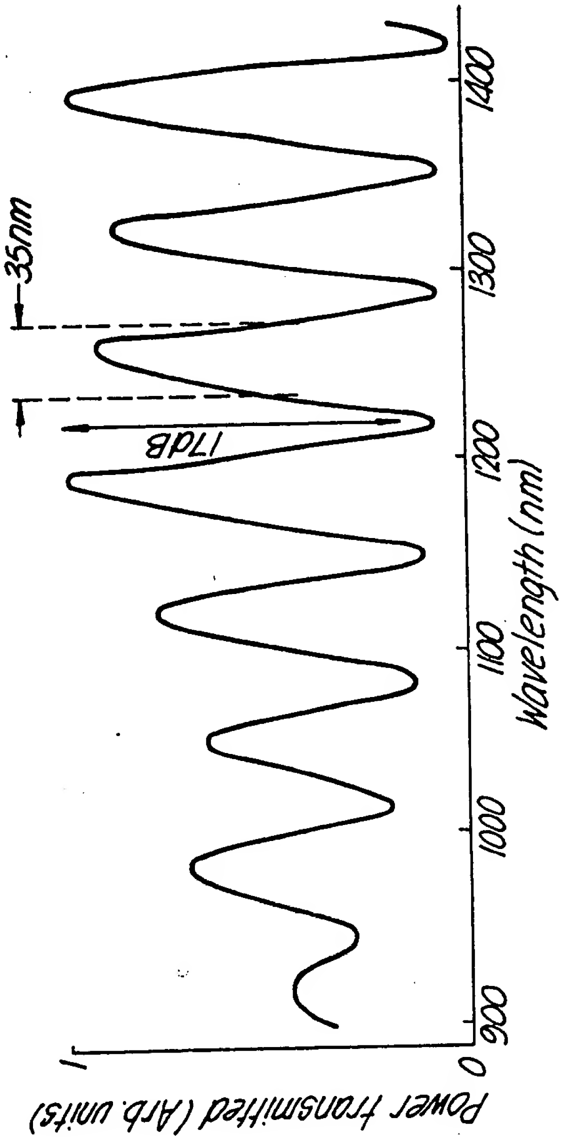


Fig. 5.

Fig. 6.


35nm
17dB
900
1000
1100
1200
1300
1400
Wavelength (nm)
0
1
Power transmitted (Arb. units)

DATE 26.6.86
RUN REF TWOTAPERS
SLITS 2

2nd.+ 8th+

	W L(NM)	INT(PPM*F.S.)
1	900	67939
2	910	67261
3	920	86283
4	930	95249
5	940	126691
6	950	145550
7	960	183899
8	970	251284
9	980	280015
10	990	310240
11	1000	343957
13	1010	311288
14	1020	339309
15	1030	328781
16	1040	317895
17	1050	301293
18	1060	291335
19	1070	289932
20	1080	306927
21	1090	349110
22	1100	395614
23	1110	453744
24	1120	512142
25	1130	553607
26	1140	558874
27	1150	539735
28	1160	487658
29	1170	390831
30	1180	299604
31	1190	236250
32	1200	184291
33	1210	133521
34	1220	111343
35	1230	96198
36	1240	88995
37	1250	86860
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54	1420	662765
55	1430	709439
56	1440	691659
57	1450	599452
58	1460	471259
59	1470	317467
60	1480	219469
61	1490	132649
62	1500	84311
66	1530	576
67	1540	37076
68	1550	52088
69	1560	42624
70	1570	30366
71	1580	34200
72	1590	21592
73	1600	3963
74	1610	474
75	1620	1750

TRAPEZIUM RULE INTEGRAL = 331057826

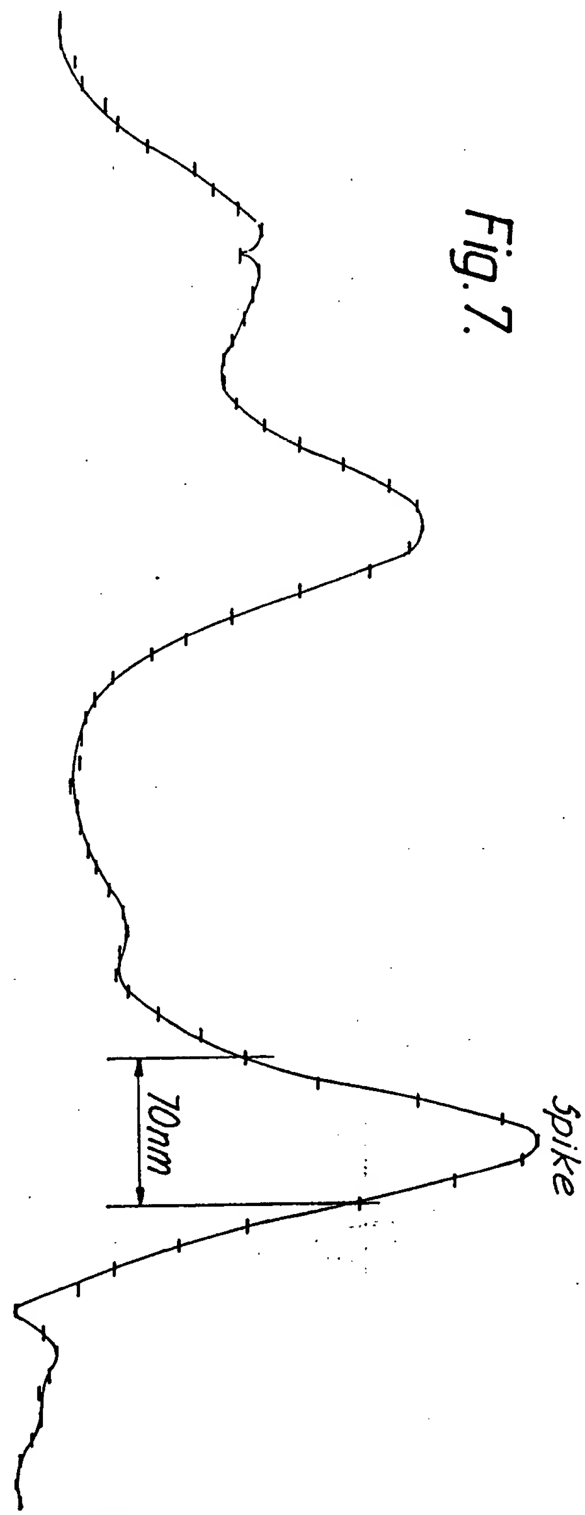

Fig.7.

Wavelength response of concotenated coaxial couplers

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SPECIFICATION

Concatenated coupler

The present invention concerns coaxial waveguide optical fibres.

It has been discovered that a coaxial coupler can be produced from optical fibres of the type having a rod waveguide surrounded by a tubular waveguide by elongating a portion of the optical fibre to reduce the transverse dimensions of the portion. This is done by mounting the fibre in a driven clamping arrangement, launching light of a predetermined wavelength at one end of the fibre and detecting the intensity of the transmitted light at the other end whilst the clamped portion of the fibre is simultaneously elongated and heated.

The intensity of the detected radiation varies cyclically as the fibre is elongated and the procedure is stopped after a number of oscillations selected to provide the appropriate transmission characteristics.

The result of this procedure, which is described in the specification of our Patent Application No. 8519086, is that it is possible, starting from an optical fibre of approximately the correct refractive index profile and dimensions to produce a coupler which is operable at a required wavelength.

The present invention has for an object to utilise this technique to manufacture filters with output responses which are tailored to specific requirements such as comb filters.

Accordingly from one aspect the present invention consists in a filter comprising a coaxial optical fibre having at least two discrete tapered sections, caused by elongation of the fibre at two separate portions, the two sections having been produced in such a manner that the fibre has specified pass-band characteristics.

From another aspect the invention consists in a process of producing a filter from a coaxial optical fibre including the steps of elongating at least two portions of the fibre to provide two tapered sections.

In order that the present invention may be more readily understood, an embodiment thereof will now be described by way of example and with reference to the accompanying drawings, in which

Figure 1 shows various refractive index profiles taken across the diameter of optical fibres suitable for use in the present invention,

Figure 2 shows a diagrammatic representation of a rig for tapering optical fibres,

Figure 3 shows a plot of the transmitted power against the extension of the fibre,

Figure 4 is a diagram representing a section through a tapered portion of the waveguide for explaining the operation of the coupler,

Figure 5 is a graph showing transmitted bandwidth against elongation for a single taper.

Figure 6 is a graph of the pass-band of a fibre which has been subjected to considerable elongation, and

Figure 7 is a graph showing the pass-band of a fibre tapered in accordance with the invention.

Referring to the drawings, Fig. 1 shows an optical fibre which defines two waveguides, a central rod waveguide which is defined by the core 2 of the fibre; and a coaxial tubular waveguide 4. As illustrated in plot A of Fig. 1, the refractive indices n_1, n'_1, of the rod and tubular waveguides are elevated relative to the refractive indices n_2, n_3 of the intermediate cladding layer 6 and the outer coating layer 8. The dimensions and refractive indices n_1 of the rod waveguide and the tubular waveguide are selected such that each will support at least one transmission mode at the design wavelength which may be, say, 1.33 or 1.55 micrometres. Plots B and C in Fig. 1 show other typical refractive index profiles for optical fibre coaxial couplers.

Light energy at the design wavelength will only be coupled from the rod waveguide to the tubular waveguide if there is precise phase-matching at this wavelength between the modes propagated in the two waveguides. Phase-matching depends critically on the refractive indexes and dimensions of the fibre profile. In most cases a fibre produced to have the required profile will not, in fact, be precisely phase-matched at the design wavelength. In order to produce the required phase-matching at the desired wavelength the fibre 10 is placed in the apparatus illustrated in Fig. 2 to taper it over a portion of its length to produce three regions of the fibre of opposite phase and mismatch at the design wavelength, so that light energy launched into one of the waveguides is substantially completely coupled to the other waveguide.

The apparatus of Fig. 2 comprises a laser light source 15 producing radiation at the design wavelength. This radiation is passed through a lens 14 to focus it onto the cleaved face of the core 2 of the fibre 10 so that light is propagated along the core of the fibre. Normally the fibre will be surrounded by an acrylate jacket which will strip any modes which start to propagate in the tubular waveguide. If such a jacket is not provided the fibre may pass through a bath of index matching fluid which will prevent light propagation along the tubular waveguide.

The fibre 10 is clamped at two spaced points along its length by clamps 16 and 18. Each

clamp is provided with a motorised driver 20, 22 to enable the clamps to be pulled away from each other to taper the portion of the fibre between them. The drives are precisely controlled so that fibre extension of the order of 1 cm can be achieved and the extension stopped at a desired point to an accuracy of less than $\simeq$20 microns. The clamps may be positioned vertically one above the other so that gravity can assist the tapering process. An oxybutane flame 23 (2–25 mm in diameter) is used to heat the fibre while the taper between the clamps is elongated.

Where the fibre is a depressed cladding fibre, that is, where n_2 is less than n_3 as shown in profile C of Fig. 1, the end of the fibre 10 is coupled to a power detector 24 which is connected to a chart recorder. If this is not the case then the power detection is provided by a microscope coupled to a vidicon camera. The power detector or microscope is focused so as to detect the power propagated along the core 2 of the optical fibre 10. If the acrylate jacket does not strip modes propagating in the tubular waveguide, a further bath of index matching fluid is provided after clamp 18 to avoid light propagating in the tubular waveguide affecting the power detector.

A typical plot produced on the chart recorder 26 is shown in Fig. 3. The plot comprises a level section 30 where a constant amount of power is being received. This is indicative of the power launched from the laser into the core being propagated along the core with little or no coupling of power into the tubular waveguide 4. After this level section 30 the received power oscillates increasingly rapidly between a series of minima 32, 34, 36 where little power is being received through the core. These minima correspond to extensions of the fibre at which the tapered portion of the fibre 10 between the clamps 16,18 is so dimensioned that there is complete energy exchange between the two waveguides. The plot produced in Fig. 3 has been shown for a considerable extension of the fibre between the clamps. However, in practice, to produce a coaxial coupler, the drive to the clamps is stopped when the recorder reaches one of the minima 34, 36, or maxima 37, 38, 39 or anywhere in between depending on the application.

If it is desired to produce a coupler which couples a desired proportion of the energy from one waveguide to the other, the taper can be stopped at other than one of the minima in order to produce the required ratio of energy transfer berween the waveguides.

The operation of the coaxial coupler produced by this tapered waveguide can be considered as analogous to a three section coupler where the mismatch ($\Delta\beta$) between the propagation constants in each section alternates in sign. The three sections of the present coupler can be identified as shown in Fig. 4. The sign of the difference between the propagation constants of the two waveguides changes between the outer portions of the taper and the central, thinnest, portion of the tapered portion. A description of the mathematics of three section $\Delta\beta$ couplers can be found in an article entitled "Switched Directional Couplers with Alternating $\Delta\beta$" by Herwig Kogelnik and Ronald V. Schmidt in IEEE Journal of Quantum Electronics, Volume QE-12, No. 7, July 1976. This article relates to couplers in which the mismatch is produced by applying electrodes with alternating potential differences across them to the coupled waveguides. However, the dimensional variation of the tapered portion can be considered to produce a similar effect.

Referring now to Fig. 5, this shows a graph of filter bandwidth versus the number of power oscillations during the fabrication of the coaxial coupler in which $\lambda = 1.52\ \mu m$ and 1 oscillation=2 beatlengths.

It can be seen that the bandwidth reduces as the number of power oscillations used during fabrication increases. Thus by having a substantial number of oscillations a narrow bandwidth can be achieved. This can be seen in Fig. 6 where by subjecting a fibre to elongation for 20 power oscillations a pass bandwidth of 35 nm has been achieved. However, from the graph it will be appreciated that the pass bandwidth characteristics are not suitable for a spike or comb filter.

It has been discovered that the required characteristics can be achieved by concatenating together two or more tapered coaxial couplers. The spectral response of a tapered coaxial coupler is approximately sinusoidal with wavelengths of period $\Delta\lambda$. Thus the wavelength response of several concatenated coaxial couplers can be represented approximately as

$$P(\lambda) \approx \left[1+\mathrm{Sin}\left(\frac{2\pi\lambda}{\Delta\lambda_1}+\theta\right)\right] \left[1+\sin\left(\frac{2\pi\lambda}{\Delta\lambda_2}+\theta\right)\right] \left[1+\mathrm{Sin}\left(\frac{2\pi\lambda}{\Delta\lambda_3}+\theta\right)\right]$$

The wavelength response is the product of the wavelength responses of the individual couplers, for fixed θ. An indication of the desired wavelength response of the individual couplers can be obtained from the above equation. For example, for θ_1, θ_2, θ_3,=0, and when

$$\Delta\lambda_1 = 2\Delta\lambda_2 = 3\Delta\lambda_3 = 4\Delta\lambda_4 \ldots = X.$$

Then a spike wavelength response is obtained within a wavelength range 2X. To obtain this result there should be successive tapered coaxial couplers each having bandwidth

$$\frac{1}{N},$$

(N=1 for the first, N=2 for the second coupler, etc.)

The tapering of the fibres is made in a manner identical to that previously described. The fibre is fixed onto a motorised jig, then tapered whilst an oxy-butane flame, for example, is applied. The output power is plotted on a chart recorder. The first tapering is stopped after two oscillations and the second taper is made a few centimeters from the first one in the same manner. The second tapering is stopped when eight oscillations have occurred in the output power i.e. the bandwidth of the second taper is half that of the first.

Fig. 7 shows the wavelength response when two typical tapers have been made in the manner described above in a single fibre. Naturally differing degrees of tapering can be used, and more than two sets of taper can be imparted to a single fibre.

The wavelength response of the double taper just described is shown in Fig. 7. Clearly, a spike is present at $\lambda=1430$ nm and there are small suppressed sidelobes above and below this peak. This is not periodic as one would expect if the couplers were of identical fibres.

Further, the passband is narrower than the passband of the individual tapers there the passband is 70 nm as opposed to a passband of 100 nm for the second individual coaxial taper (as can be derived from the graph of Fig. 5).

For a maximum througput at the fabrication wavelength, it should be ensured that the tapering is stopped to a maximum power for both tapers.

Finally, the summary of the advantages of such a device is as follows:

1. A narrow spike or comb filter like wavelength response can be obtained which is narrower than the individual taper response.

2. The filter is of low loss, all fibre.

3. Simple fabrication on a standard coupler fabrication jib.

Filters of the type produced in accordance with the invention can be used in a number of different applications. For example, in a wavelength drop-off filter in a wavelength division, multiplexed communication link or to separate a single line from a multilongitudinal mode laser.

CLAIMS

1. A filter comprising a coaxial optical fibre having at least two discrete tapered sections caused by elongation of the fibre at two separate portions, the sections having been produced in such a manner that the fibre has specified pass-band characteristics.

2. A filter as claimed in Claim 1, wherein each tapered section is fabricated by heating the section whilst elongating the fibre, launching lifght down one end of the fibre, monitoring the light transmitted through the fibre and stopping the elongation after a selected number of power cycles of the monitored light.

3. A filter as claimed in Claim 2, wherein the fibre comprises a central rod waveguide, an intermediate cladding, a tubular waveguide and an outer coating layer.

4. A filter as claimed in Claim 3, wherein the refractive indices of the rod and tubular waveguides are higher than that of the intermediate cladding and the outer coating layer.

5. A filter as claimed in any one of Claims 2, 3 or 4, wherein each tapered section has a bandwidth determined during its manufacture by the number of power oscillations monitored during the fabrication of the taper, successive tapered sections having reduced bandwidths.

6. A filter as claimed in Claim 5, wherein there are more than two tapered sections.

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